Chapter - 1

GEOLOGICAL SETTING
CHAPTER ONE

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I. GENERAL GEOLOGY OF ARAVALLI MOUNTAIN BELT

The Indian shield consists of various crustal blocks with distinct lithotectonic characteristics (Rogers 1986; Naqvi and Rogers 1987), largest among these is the Aravalli craton, which occupies its north western part (Figure-1:a). It is bounded by the Main Boundary Thrust (MBT) of Himalayan foot hills in the north, the Cambay basin in the south-west and the Son-Narmada lineament in the south and south-east. The eastern boundary of this craton is marked by the Great Boundary Fault (GBF) and the western margin is covered by recent deserts of Thar (Naqvi and Rogers 1987). The rocks of this craton range in age from 3300 Ma to 550 Ma (Crawford and Compston 1970; Macdougall et al. 1983, 1984; Gopalan et al. 1990), indicating that the area was tectonically active from early Archaean to end of Proterozoic.

The western margin of this craton is marked by the presence of NE-SW trending Aravalli mountain range, which runs from Delhi in the north to little north of Ahmadabad in the south for about 700 km with a variable width of about 30 to 200 km. It is made up principally of three tectonostratigraphic units with several granitic, mafic and ultramafic extrusives and intrusives of different ages. The oldest among these is the Banded Gneissic Complex (BGC, Heron 1953) varying from about 3300 to 2500 Ma (Roy 1990; Gopalan et al. 1990). The BGC served as basement for two younger units, i.e., the early Proterozoic supracrustal rocks of Aravalli Supergroup (2500-1900 Ma, Roy 1990) and the middle Proterozoic supracrustals of Delhi Supergroup (1900-1450 Ma, Roy 1990). Although, the distribution, mutual correlation and stratigraphy of these units are still a matter of debate, yet there is a general agreement among the geoscientists on BGC being the basement of the Proterozoic supracrustal sequences.
The Banded Gneissic Complex (BGC)

The BGC, which is one of the best studied units of this region, consists some of the oldest Archaean rocks (about 3.3 Ma, Gopalan et al. 1990). It is represented by contrasting rock types which includes biotite/hornblende gneisses, granitic rocks, amphibolite, aluminous paragneisses, quartzite, marble, calc-silicate rocks and pegmatites. However, the granitoid gneisses of different compositions and amphibolites form the bulk of the basement. In general, the BGC comprises of two tectonic blocks: the northern block and the southern block, roughly with respect to Nathdwara (Sen 1980). The rocks of the northern block have been metamorphosed under pressure-temperature conditions of the amphibolite to granulite facies, while the rocks of the southern block are metamorphosed up to the grade of amphibolite facies. Although, the antiquity of the basement is proved by the presence of 3300 Ma old rocks (Gopalan et al. 1990), there are apparently no true Archaean greenstone belts as reported from southern part of the Indian shield (Naqvi and Rogers 1987). However, some isolated remnants of low grade Archaean rocks resembling greenstone belts have been recognized (Sinha-Roy 1985; Upadhyaya et al. 1992; Ahmad and Tarney 1994). The youngest unit of the BGC is the Berach granite and its equivalent rocks which have yielded a Rb/Sr isochron age of 2600 Ma (Chaudhary et al. 1984).

The Aravalli Supergroup

This supracrustal sequence of early Proterozoic age occurs in two adjoining major belts: the Bhilwara belt and the Udaipur-Jharol belt. The Bhilwara belt is exposed as a NE trending wedge shape area between Great Boundary Fault (GBF) in the east and Karera in the west. This belt comprises several sub-parallel N-S trending linear belts separated from each other by zones of BGC. In general, these belts consist of quartzite, metaphyllites, carbonates, BIF and gray ashes interlayered with mafic volcanics.

The Udaipur-Jharol belt is exposed as an inverted “V” shaped area with tapering end near Nathdwara (Figure-1:c). The middle part of the belt is marked by
N-S trending Rakhabdev lineament (Figure-1:c). This lineament marks the boundary between shallow water metasediments of Udaipur belt in the east and deep water metasediments of Jharol belt in the west. A more detailed account of the geology of this belt is presented separately in this chapter.

The Delhi Supergroup

The rocks of Delhi Supergroup occur to the west of Jharol belt, where they form a linear belt which extends all along the length of Aravalli mountain belt. The belt narrows near the centre and widens towards both the ends (Figure-1:b). Heron (1953) sub-divided his "Delhi System" into two stratigraphic units. The lower Alwar Group is dominantly arenaceous consisting of arkose, quartzite, conglomerate and mafic volcanics. The upper Ajabgarh Group is mainly calcareous comprising of calc-schist, calc-gneisses with interlayered mafic volcanics and tectonized bodies of mafic and ultramafic rocks, the latter is considered as Phulad ophiolites (Sinha-Roy 1988; Volpe and Macdougall 1990). The Delhi Supergroup is considered to be the youngest unit of Aravalli mountain range.

II. DISTRIBUTION OF MAFIC-ULTRAMAFIC ROCKS IN ARAVALLI MOUNTAIN BELT

In Aravalli mountain belt, mafic and ultramafic rocks occur at different stratigraphic levels. In this region the oldest volcanic activity is represented by early Archaean (3300 Ma) amphibolites occurring within the Banded Gneissic Complex (Gopalan et al. 1990). The next phase of magmatic events is represented by early Proterozoic komatiitic and tholeiitic lava flows occurring at the base of Aravalli Supergroup in its type area of Udaipur belt (Ahmad and Rajamani, 1988, 1991; Raza and Khan 1993). Ahmad and Tarney (1994), however, have considered the basal Aravalli mafic rocks as late Archaean. Equivalent of these volcanic rocks are found in basal part of various sub-belts of the Bhilwara belt (Roy et al. 1981; Deb et al. 1989). In the Jharol belt this volcanic activity is restricted along a lineament known
as Kaliguman lineament. Here the magmatism is represented by metavolcanics (Bagdunda volcanics) which occur at its basal part and are well exposed in the area around Bagdunda (24°41':73°32') (Sharma et al. 1988), and the Gopir volcanics and dykes occurring between Gogunda (24°45':73°34') and Damana (24°22':73°26') (Abu-Hamatteh et al. 1994). The mafic-ultramafic rocks of Kaliguman lineament are developed along the central part of Jharol basin and the ultramafic rocks of Rakhabdev lineament which are developed along its eastern margin are younger than the Bagdunda volcanics as they occur at a comparatively higher stratigraphic level (Tables-1 and 2).

The next younger phase of the Aravalli mountain belt volcanism is represented by mafic volcanic rocks, which are found at two stratigraphic levels in the metasedimentary sequence, of Delhi Supergroup. The older rocks are those which occur at the base of Alwar group (1700-1500 Ma., Volpe and Macdougall 1990) and younger one occur within the Ajabgarh group (850-750 Ma., Volpe and Macdougall 1990). The Alwar group volcanism is best represented by lava flows of Byana and Tehla areas of the north-eastern Rajasthan. The younger phase of Delhi volcanism is more widespread as indicated by the occurrence of metavolcanics and metasedimentary rocks of Ajabgarh Group in a linear belt approximately 450 km long and up to 30 km wide from Khetri in the north to Deri and Ambaji in the south.

III. GEOLOGY OFUDAIPUR-JHAROL BASIN

The triangular area bounded by Bhilwara belt in the east and Delhi belt in the west (Figure-1:c) contains the rocks of Aravalli Supergroup which shows development of two distinct lithofacies associations, i.e., a carbonate-bearing shelf facies of Udaipur belt in the east and a carbonate-free deep water facies of Jharol belt in the west (Roy et al. 1988, 1993). The metasedimentary rocks of Jharol belt are considered to be deep water, distal-trubidite facies of shallow sediments of Udaipur belt (Roy and Paliwal 1981). In view of the similarity of tectonic trends and deformational history these two belts are considered to represent two separate
segments of a single basin (e.g., Deb and Sarkar 1990). Although, generalized geological framework of this basin has been given by many workers (Heron 1953, Raja Rao et al. 1971; Gupta et al. 1980), a detailed stratigraphic evolution of the basin has been worked out by Roy et al. (1988). Recently, two regional stratigraphic correlation schemes have been proposed (Roy et al. 1993; Sinha-Roy et al. 1993) as given in tables (1) and (2).

According to Roy et al. (1993) (Table-1), the shelf sequence of the Udaipur belt is sub-divided into two groups, i.e., lower and upper groups. The lower group starts with conglomerates, quartzite and basic volcanics referred to as Delwara Formation. This formation is overlain by a sequence of rocks comprising phyllites (locally carbonaceous), dolomite, quartzite and stromatolitic phosphorites (Jhamarkotra Formation). The upper group contains graywacke-slate-phyllite, rythmite, lithic-arenites at the base, overlain by quartzite, dolomite and silty arenite in the middle and slate phyllite at the top. The rocks of the Udaipur belt thin out towards the north and occur as irregular seams between the BGC and Delhi belt rocks. The grade of metamorphism does not exceed green schist facies, except in rare instances (Naha et al. 1967). No felsic magmatism is reported in Aravalli Supergroup.

The Jharol belt is bounded by the Udaipur belt in the east and Delhi belt in the west. It comprises of a thick column of phyllites and lutites with bands of quartzite and limestones (Sugden et al. 1990). Although, Jharol belt comprises mainly of deep water sediments, its basal part has an apparent resemblance with shelf facies basal formation rocks of Udaipur sequence. In Bagdunda area, an inlier of BGC occurs as an oval shaped exposure (Sharma et al. 1988). Here, the succession begins with interlayered fine grained quartzite bands (chert?) and mafic flows followed by thick sequence of meta-argillites containing mafic-ultramafic flows and fine quartzite bands up to 100 m thick in the upper part (Sugden 1987 as given in Drury 1990). In Jharol belt the mafic-ultramafic rocks occur in two N-S trending parallel belts. The first belt occurs between Rakhabdev in the north and Dungarpur in the south (Figure-1:c), and has been referred to as Rakhabdev lineament. This belt roughly coincides
with the contact between Udaipur and Jharol belts and is characterized by the occurrence of huge bodies of ultramafic rocks. During the present investigation, no mafic components were found in this belt and it appears to be comprised essentially of ultramafic rocks. However, the presence of some highly altered mafic magmatic rocks cannot be ruled out. The second belt, which was earlier considered to be made up entirely of ultramafic rocks, was found to consist of both mafic and ultramafic rocks, occurring along the central part of the Jharol basin. This belt runs between Gogunda in the north through Jharol to Damana in the south. In a recently published map of Geological Survey of India, this belt is shown as Kaliguman lineament (Gupta et al. 1980, Figure-1:c).

Although the relationship between various units of Jharol belt is not very clear, the lithostratigraphic characteristics of Jharol belt may be summarized as follows:

Basal fine grained quartzite-metavolcanics unit, which is exposed around Bagdunda village forms an oval shaped outcrop in the middle of the basin (Figure-1:d). The unit overlies the gneissic basement as it has unconformable contact relationship with the Banded Gneissic Complex (BGC). The mafic rocks, referred to as Bagdunda amphibolites by Sharma et al. (1988), are found intercalated with thin bands of basal fine grained quartzite (chert?) (Plate-1).

The basal unit is followed by a thick sequence of garnetiferous mica-schist (meta-pelites) which forms the major part of Jharol belt. The garnetiferous mica-schist is followed by thick sequence of massive fine grained quartzite (chert?) and mafic-ultramafic rocks which appear to be occupying the upper levels of the Jharol belt stratigraphy. The ultramafic rocks are sometimes associated with chert bands (Mohanty et al. 1993). Isolated ultramafic rocks (talc-chlorite schist) are also found sporadically within the garnetiferous mica-schist. They occur either as continuous bands or in the form of isolated lenses, probably due to transverse faults (Sychanthavong and Singh 1994).
IV. FIELD OCCURRENCE OF THE MAFIC AND ULTRAMAFIC ROCKS OF JHAROL BELT

The mafic rocks of Jharol belt as discussed in previous sections appear to occur at two tectono-stratigraphic levels. The older ones are those found as intercalated flows within the basal quartzite near Bagdunda area. The younger mafic rocks are those which occur associated with ultramafic rocks within the garnetiferous mica schist at a higher stratigraphic level. Both these mafic units are folded, faulted and metamorphosed along with the associated metasediments. In literature, these mafic-ultramafic rocks have been generally described as ultramafic intrusions by previous workers. Heron (1953) considered them as sills, whereas Patel and Merh (1967) believe that they are intruded during terminal phase of Aravalli sedimentation. Some workers described these rocks as an obducted oceanic crust (Sychanthavong and Desai 1977; Sen 1981; Sinha-Roy 1988; Mohanty et al. 1993). Roy et al. (1988) consider their emplacement as synsedimentary, at terminal phase of Aravalli sedimentation, emplaced at the time of deepening of basins. In a recent publication, Sugden et al. (1990) suggested that the emplacement of these rocks was controlled by the rupture and break up of the BGC along the Rakhabdev lineament. Subsequently, with the thinning of the crust which become site for asthenospheric upwelling the ocean crust was formed. These authors also believed that the spreading centre as well as the basement rock were buried by Jharol sediments which are rarely exposed, for instance, in Bagdunda area.

The present study suggests that, the linear belt which runs along the central part of the basin between Gogunda and Damana consists of both mafic and ultramafic rocks (Abu-Hamatteh 1992; Abu-Hamatteh et al. 1994). Although the deformation and metamorphism have obliterated most of their primary mineralogy, textures and structures, yet some relict features are preserved which suggest that these mafic-ultramafic rocks erupted and intruded contemporaneously with sedimentation of Jharol basin.
Bagdunda Volcanics

Bagdunda volcanics which are described earlier occur as amphibolites (Sharma et al. 1988) are intercalated with fine grained quartzite bands (Plate-1) which are sometimes of fuchsitic nature. This quartzite-volcanic unit overlies the BGC with unconformable contact relationship, and appear to show apparent similarities with the basal unit of Udaipur belt (Roy and Paliwal 1981) although the quartzites in the latter belt are coarse grained as compared to those of Jharol belt. The metavolcanics are generally light to dark greenish in colour, often co-folded with the associated micaeous quartzite. In addition to their intercalation with quartzite (Plate-1) the extrusive nature of these basal mafic volcanics is illustrated by the presence of stretched and deformed amygdules (Plate-2) which are found on the road cutting between Bagdunda and Gogunda. At some localities these rocks show alternative dark and light bands with well developed schistosity plains. The samples of these mafic rocks collected from this area are referred to as Bagdunda volcanics (BAV) throughout the text.

Gopir Volcanics, Dykes and Associated Ultramafic Rocks (Kaliguman Lineament)

The younger mafic rock which are found associated with ultramafic rocks occur as minor flows and dykes and are well developed around Gopir and Challi areas in the southern part of Jharol belt.

In the northern part of the belt, huge ultramafic bodies are exposed near Modri village and extends up to little north east of Bagdunda village, for about 8 km. Near Modri the ultramafic rocks are found to be associated with minor carbonate and chert bands. The ultramafic rocks are fine to medium grained with light greenish to grey colour. They have undergone green schist facies metamorphism and are serpentinized and intensively deformed.

South of Modri, near Jhameshwarjee temple, the ultramafic rocks are exposed almost in N-S direction. They show intercalation with fine grained almost glassy
Plate-1 Intercalation of Bagdunda volcanics (basal Jharol volcanics) with the basal quartzites near Bagdunda.
Plate-2  Deformed and stretched amygdules in Bagdunda volcanics.
blackish quartzite bands (Plate-3) which are up to 25 m thick. These quartzites have gradational contact with the ultramafics while the latter have a sharp contact with the mica-schist. At places the ultramafic rocks have pitted appearance (Plate-4) probably indicating removal of material due to secondary process. They are generally fine grained, but at some localities the crystals of actinolite-tremolite are large enough to be measured by scale, for instance, near Majam village east of Bagdunda. The ultramafic rocks reappear south of Bagdunda and extends up to the southern part of the belt beyond Damana area.

In Challi area (south of Bagdunda), the ultramafics are associated with mafic rocks near Undithali village. The ultramafics are greenish in colour, compact and talcose and are fine grained rocks. The relicts of possible pillow lava structure (Plate-5) are found around Challi area at Palayal Ghati mines along the road connecting Gogunda with Jharol. Further south, near Gopir village, this belt contains both mafic and ultramafic rocks. The mafic rocks of Gopir are very hard and massive containing no talc or serpentine, but the ultramafic rocks are green coloured, serpentinized and talcose rocks. Here the mafic rocks are of two varieties, the predominant type is fine grained rocks with well developed schistosity (probably representing flows) and the other being hard, massive and coarse grained probably representing dykes. The mafic rocks from this area are referred to as Gopir volcanics (GRV) and Gopir dykes (GRD).

Ultramafic Rocks of the Eastern Margin of Jharol Basin (Rakhabdev Lineament)

The ultramafic rocks of Rakhabdev lineament are well developed around Rakhabdev, Dungarpur and Kherwara in the south-eastern part of Jharol belt (Figure-1:c). In this area, no mafic rocks are found associated with the ultramafic rocks. These ultramafic rocks consist mainly of serpentine with widespread alteration to talc, carbonate, chlorite and actinolite-tremolite assemblages. They are concordantly emplaced within phyllite, mica-schist, quartzite and dolomite with often sheared and faulted contacts (Chattopadhyay and Gangopadhyay 1981). They
Plate-3  Jharol ultramafics intercalated with quartzite bands near Jameshwarjee temple.
Plate-4  Pitted appearance in Jharol ultramafics near Jameshwarjee temple, indicating removal of some material during post crystallization processes.
Plate-5  Some suspect deformed pillows in Jharol ultramafics around Challi area.
are generally massive to irregularly fractured, but sometimes they are strongly foliated and tightly folded. They occur as huge bodies aligned in the N-S direction with tens of km in length and 2-3 km in width. At some places near Paraya Goan around Rakhabdev town, they are very fine grained rocks (antigorite) having flow characteristics (Plate-6).

V. AGE AND CORRELATION

Till date, no radiometric data is available on the rocks of Jharol belt and thus, the age of these mafic-ultramafic rocks has been variously interpreted on the basis of lithologic and structural controls of the area. There are two views regarding the mode of occurrence and emplacement of these mafic-ultramafic rocks.

As discussed in the previous sections, according to Heron (1953) these mafic-ultramafic rocks are sills, suggesting that they are younger than the Aravalli sediments. Patel and Merh (1977), though supported the intrusive nature of these rocks but observed that probably they were intruded at the culmination stages of Aravalli sedimentations which implies that they are younger than Aravalli sediments but relatively older than the age assigned by Heron (1953). Some other workers, viz, Sychanthavong and Desai (1977), Sen (1981), Sinha-Roy (1988) and Mohanty et al. (1993), believe that these mafic-ultramafic rocks represent an obducted ancient oceanic crust.

Contrary to the above observations, Roy et al. (1993) and Sugden et al. (1990) considered emplacement of these mafic-ultramafic rocks contemporaneously with the deposition of Aravalli sediments, at the time when the basin was undergoing deepening. This implies that the mafic-ultramafic rocks of Jharol belt are of Aravalli age.

The similarity of the basal stratigraphy of Jharol belt in the Bagdunda area (Sharma et al. 1988) with that of the basal unit of the main Udaipur belt, in the type area, suggests that the volcanic rocks occurring around Bagdunda are equivalent to the basal Aravalli volcanics (about 2000 Ma-2600 Ma; appendix-I). On the other
Plate-6  Jharol ultramafic rocks exposed around Rakhabdev area.
hand, the mafic-ultramafic rocks (Kaliguman lineament) of the central part of Jharol belt, which occur at higher stratigraphic level, are of comparatively younger age.

Several isotopic studies document the possible ages of the various litho-units of Aravalli region, these are summarized and presented in appendix-I.

Available Sm/Nd model ages indicate that the basal Aravalli volcanics may not be older than 2600 Ma (Macdougall et al. 1984). The Berach granite, which has been considered as the youngest unit of the BGC, has yielded a Rb/Sr isochron age of about 2500 Ma (Crawford 1970). The Dharwal granite, which is believed to have been emplaced during the earliest deformation of Aravalli rocks (Naha et al. 1967), has been dated at 2000 Ma (Gopalan 1984). On the bases of these evidences it may be inferred that the Aravalli sequences of Udaipur and Jharol belts developed during the period between 2500 Ma and 2000 Ma.